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Adult Female Hip Bone Density Reflects Teenage Sports–Exercise Patterns But Not Teenage Calcium Intake

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ABSTRACT. ***Objective.*** **To examine how cumulative teenage sports histories and time-averaged teenage calcium intake are related to total body bone mineral gain between ages 12 and 18 years and to proximal femur bone mineral density (BMD) at age 18 years.**

Design. **Longitudinal.**

Setting. **University Hospital and local suburban community in Central Pennsylvania.**

Study Participants. **Eighty-one white females in the ongoing Penn State Young Women's Health Study.**

Outcome Measures. **Total body and proximal femur (hip) bone measurements by dual energy radiograph absorptiometry; nutrient intakes, including calcium, from 33 days of prospective food records collected at regular intervals between ages 12 and 18 years; and self-reported sports–exercise scores between ages 12 and 18 years.**

Results. **Cumulative sports–exercise scores between ages 12 and 18 years were associated with hip BMD at age 18 years (r = .42) but were not related to total body bone mineral gain. Time-averaged daily calcium intake, which ranged from 500 to 1500 mg/day in this cohort was not associated with hip BMD at age 18 years, or with total body bone mineral gain at age 12 through 18 years.**

Conclusions. **The amount of physical activity that distinguishes a primarily sedentary teenager from one who engages in some form of exercise on a nearly daily basis is related to a significant increase in peak hip BMD.** ***Pediatrics*** **2000;106:40–44;** ***peak hip bone density, teenage sport histories, osteoporosis prevention.***

ABBREVIATION. BMD, bone mineral density.

The risk of osteoporotic fracture is determined by low peak bone mass, accelerated bone loss, or both.[1] The average woman gains 40% to 50% of her skeletal mass, ie, ~1000 g of bone mineral, during adolescence.[2–5] Epidemiologic investigations point to nutrition and exercise as the modifiable determinants of peak bone mass.[6–11] Thus, longitudinal studies with healthy pubertal and adolescent females are necessary to investigate the influences of nutrition and physical activity on bone gain.

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The possible influence of adolescent calcium intake on bone gain has been examined with many retrospective studies and several long-term calcium supplementation trials. To date, there is no convincing evidence that calcium intake above 900 mg/day results in significant long-term increases in peak bone mass.[12–18] Cross-sectional studies of athletes and nonathletes show that training results in increased bone mineral densities (BMDs) and prospective exercise programs conducted with girls and premenopausal women have shown that strength training and high impact activities lead to increased bone densities.[19–25] Quantitative data on the effect of self-selected sports and exercise activities on adolescent bone gain and peak bone mass have been lacking. The objective of this study was to use longitudinal datasets to learn how bone gain and bone density among healthy white girls are related to nutrient intake, anthropometric changes, and self-selected sports–exercise activities from ages 12 to18 years.

METHODS

Subjects and Retention

The Penn State Young Women's Health Study is a continuing, prospective epidemiologic study started in 1990 with the enrollment of 112 healthy premenarchal females. This cohort is close in age. They were 11.9 ± .5 years of age at entry (visit 1) and 17.9 ± .5 years of age 6 years later. The study population is representative of white female adolescents attending public school in central Pennsylvania. The details of the recruitment; baseline anthropometric, endocrine, and bone measurements; and the early effects of a calcium supplementation trial on bone gain have been reported.[26,27] The study was approved by the Pennsylvania State University College of Medicine Institutional Review Board, and parents of participants provided informed consent. During the first 4 years of the study, as participants progressed from 12 to 16 years of age, they were seen every 6 months. After 16 years of age, participants have been seen yearly.

During the first 6 years of this study, 84 of the original 112 participants (75%) remained in the study. No differences were noted in terms of baseline age, height, or weight, or in terms of baseline bone measurements between those who dropped out and those who remained in the study. All measurements in this report are based on the 81 participants for whom we have uninterrupted serial measurements. (Three of the 84 remaining participants have interrupted records because of pregnancies.)

Nutrient Assessment

Prospective 3-day diet records were completed at baseline and every 6 months for the first 4 years and yearly thereafter. The records were analyzed with Nutritionist III, Version 7.0 and Nutritionist IV, Version 3.0 software (FirstDataBank, Inc, San Bruno, CA). We calculated time-averaged daily calcium intake for each participant using her 11 regularly completed, 3-day diet records between ages 12 and 18 years and from her calcium supplementation data. This cohort participated in a double-blind, random-

ized, placebo-controlled calcium supplementation trial during ages 12 to 16 years.[27] Residual pill counts made every 6 months during the intervention periods allowed us to calculate calcium intake attributable to the supplementation program.

Body Composition Measurements

Total body bone mineral content and mineral density and percent body fat measurements were made by dual energy radiograph absorptiometry using Hologic equipment (Hologic Corp, Waltham, MA) and standard procedures.[28] Each participant underwent a total body scan using pencil beam mode and the manufacturer's tissue phantom at each visit. Beginning at age 16 years, both proximal femurs were scanned yearly using the array mode and the Osteodyne Hip Positioner (Osteodyne Research, Triangle Park, NC). The average proximal femur (hip) BMD is reported.

Fitness Measurements

Participants were tested yearly for aerobic power, strength, and flexibility. Fitness results from the age 18 years clinic visits are used in this report. Aerobic power was measured as estimated maximum oxygen consumption on a Monarch bicycle ergometer (Monarch AB, Varberg, Sweden). A graded 4-stage protocol was used with the target endpoint being the participant's heart rate reaching 85% of her age-adjusted maximal heart rate. Strength was measured with a grip dynamometer (Lafayette Instruments, West Lafayette, IN). Additional fitness measurements included the number of abdominal curl-ups done in 1 minute, the number of modified push-ups done in 1 minute, and the number of seconds (up to 90) that participants could sit with their back to a wall with their upper legs parallel to the floor and their lower legs vertical to the floor (wall-sit).

Sports–Exercise Scores

The sports–exercise questionnaire used in this study was based on existing instruments.[29,30] In brief, each questionnaire listed 28 activities including: 1) school-based activities, eg, soccer, basketball, cross-country, and marching band; 2) outside-of-school organized activities, eg, swimming, ballet and other dance programs, and aerobic classes; and 3) individual activities, eg, walking, running, martial arts, and tennis. For each activity a participant took part in, she used the following scale to record frequency: 0 = less than once per month; 1 = once per month; 2 = once per week; 3 = 2 or 3 times per week; and 4 = 4 or more times per week. Participants recorded participation by activity and frequency for grades 6 to 12, ie, ages 12 to 18 years. The cumulative sports–exercise score was the arithmetic sum, in arbitrary units, for the 6 years covered by the questionnaires. The range of the 6-year sports–exercise scores was 2 to 291. An example of a relatively sedentary participant with a cumulative score of 40 was a member of a seasonal marching band who had occasional individual activities. Participants who engaged in 2 seasonal school sports for 4 or more years and also engaged in occasional individual activities had cumulative scores of 100 to 120. Individuals with scores above 170 had year-round involvement in varsity school sports. The sports–exercise questionnaire and representative examples of 6-year activities are available from the corresponding author by request.

Statistical Analysis

Statistical analyses were performed using SAS (SAS Institute, Cary, NC).[31] Descriptive statistics, such as means and standard deviations, are reported for all variables. Pearson correlation coefficients were calculated to investigate the relationships between those various predictor variables that were normally distributed and the 2 response variables (total body bone mineral content gain and hip BMD at age 18 years). Kendall correlations were used for those variables not normally distributed. Multiple regression models were generated using stepwise and backward elimination regression methods. If the 2 multiple regression techniques disagreed in their results, then the results reported are based on the method that yielded the smaller model. The R^2 coefficient and the partial correlation coefficients are reported from each multiple regression model.

RESULTS

Descriptive statistics for the study group at age 12 and 18 years are presented in Table 1. As the study subjects went from 12 to 18 years of age, they gained, on average, 10% of their height, 29% of their weight, 42% of their total body bone mineral content, and 19% of their total body BMD. Univariate correlations of nutrient intake, physical size, fitness measurements, and sports–exercise scores with ages 12 to 18 years total body bone gain and hip BMD at age 18 years are shown in Table 2. Significant positive correlations with hip BMD at age 18 years were observed for the sports–exercise score (r = .42; P = .0001); body weight at age 18 years (r = .40; P = .0002); and the wall-sit score (r = .28; P = .01). For total body bone gain during ages 12 through 18 years, significant positive relationships were observed for height at age 18 years (r = .23; P = .04) and weight at age 18 years (r = .44; P = <.0001). Correlational analyses regarding average daily nutrient and food group consumption as calculated from the 33 days of food records collected between ages 12 and 18 years did not reveal other associations with either hip BMD at age 18 years or total body bone mineral gain. For example, the correlation between daily calcium intake and total body bone mineral gain was r = .07 and P = .55. We also examined correlations between calcium intake, bone gain, and

TABLE 1. Descriptive Statistics of the Study Group at Ages 12 and 18 Years (n = 81)

Variable	Age 12, $\bar{x}$ ± SD	Age 18, $\bar{x}$ ± SD
Age	11.9 ± .5	17.9 ± .52
Height, cm	149.0 ± 6.7	166.0 ± 5.9
Weight, kg	41.5 ± 7.4	58.2 ± 8.0
Body mass index, kg/m^2	18.6 ± 2.3	21.1 ± 2.5
% body fat	27.7 ± 3.7	24.9 ± 4.6
TBBMC, g	1276 ± 272	2192 ± 297
TBBMD, g/cm^2	.88 ± .06	1.07 ± .07
Proximal femur BMD, g/cm^2	NA	.98 ± .10
Total kcal/d	1874 ± 472	1824 ± 626
kcal/kg/d	46.4 ± 13.0	31.8 ± 11.9
Protein, g/d	69.2 ± 21.1	67.6 ± 20.6
Carbohydrates, g/d	252.2 ± 65.6	274.1 ± 116.9
Total fat, g/d	69.7 ± 22.7	54.0 ± 22.1
Total calcium, mg/d	919 ± 409	902 ± 372
Age of menarche	NA	13.3 ± .8

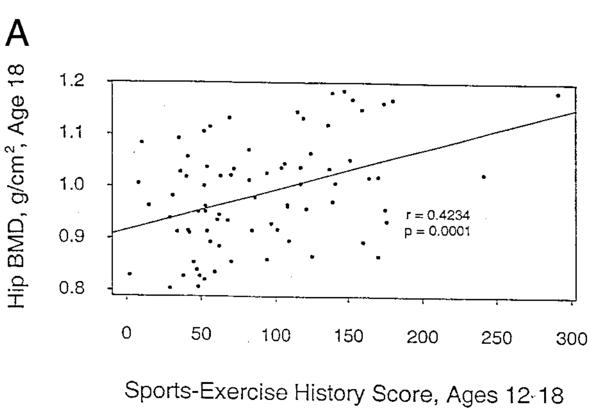
NA indicates not applicable; TBBMC, total body bone mineral content; TBBMD, total body bone mineral density; SD, standard deviation.

TABLE 2. Pearson and Kendall Correlation Coefficients of Nutrient Intake, Physical Size, Physical Fitness and Sports–Exercise Scores With Bone Measurements

Variable	Proximal Femur BMD at Age 18 Years		Total Body Bone Mineral Gain, Ages 12 to 18 Years		Total Body BMD Gain, Ages 12 to 18 Years	
	r	*P* Value	*r*	*P* Value	*r*	*P* Value
Age at visit 11	.24	.03	−.38	.0005	−.22	.05
Height, age 18 y	.21	.07	.23	.04	.07	.54
Weight, age 18 y	.40	.0002	.44	<.0001	.24	.03
Sports–exercise score	.42	.0001	.12	.28	.02	.88
Estimated maximum oxygen consumption	.12	.27	−.22	.05	−.08	.45
Push-ups	.14	.23	−.22	.05	−.11	.35
Curl-ups	.16	.15	.17	.13	.23	.04
Wall-sit	.28	.01	−.02	.85	.06	.57
Hand-grip	.06	.58	.07	.54	.01	.93
Total calcium intake/d	.10	.36	.07	.56	.07	.55
Total calories/d	.17	.12	.10	.37	.08	.49
kcal/kg/d	−.16	.15	−.0002	1.0	.06	.62
Age of menarche	−.19	.09	.15	.19	.04	.75

hip BMD at age 18 years after normalizing daily calcium intake as milligrams of calcium per kilogram of body weight, or as milligrams of calcium per 1000 kcal, and as a calcium/protein ratio. None of these adjustments produced a significant correlation between calcium intake and either bone gain or hip BMD at age 18 years. In Fig 1A, individual hip BMD values at age 18 years are plotted against each individual's cumulative sports–exercise score. Deletion of the decile ($n = 8$) of individuals with the highest sports–exercise scores does not affect the relationship, which becomes $r = .41$ and $P = .004$. Figure 1B shows that there is no relationship between hip BMD values at age 18 years and the 6-year time-averaged daily calcium intakes.[12–18] To learn whether physical activity during a specific interval in adolescence was more strongly related to hip BMD at age 18 years, we also analyzed our data by 2-year intervals: namely ages 12 to 14, 14 to 16, and 16 to 18 years. The relationship between the sports–exercise scores and hip BMD at age 18 years was the same for each 2-year interval. It is noted that although increased peak hip BMD was related to the cumulative sports–exercise score, it was not related to aerobic capacity.

Multiple regression analyses were performed to determine the significance of each variable correlated with one of the bone measurements after adjusting for the effects of the other variables. The results of these analyses, presented in Table 3, show that the sports–exercise score, the wall-sit score, and weight at age 18 years remained significant predictors of hip BMD at age 18 years. For total body bone mineral gain during ages 12 to 18 years, age of menarche and weight at age 18 years were positive predictors.



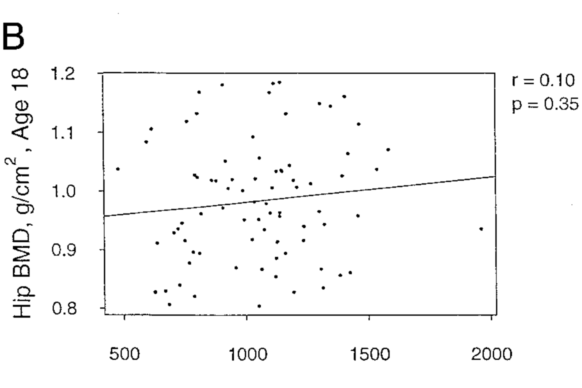


Fig 1. A, Hip BMD at age 18 years of each subject versus her cumulative sports–exercise score for ages 12 to 18 years ($r = .42$; $P = .0001$). B, Hip BMD at age 18 years of each subject versus her 6-year time-averaged calcium intake (12–18 years old; $r = .10$; $P = .36$).

DISCUSSION

Because the skeleton is 40% calcium by weight and diminishes with disuse, it is logical that calcium intake and physical activity are necessary to optimize bone gain during adolescence. Our study focused on the contribution of teenage calcium intake and teenage physical activity to the total body bone mineral gain and peak hip BMD—the latter being the best-known predictor of hip fracture. The recent literature dealing with calcium intake, physical activity, and adolescent bone changes has been well-reviewed[8–10]; and from these reviews, we may draw 3 conclusions: 1) although there is still debate about the amount of dietary calcium needed to optimize peak bone mass, there is no convincing evidence that >900 mg/day is needed; 2) weight-bearing physical activity is associated with increased adolescent bone gain; and 3) the variation in study protocols makes study-to-study comparisons difficult, because the cohorts in previ-

TABLE 3. Multiple Regressions of Bone Variables With Multiple Predictors

Response Variable	Predictor Variables	β Coefficient (95% Confidence Interval)	Partial Correlation	*P* Value
Proximal femur BMD, R^2 = .34	Sports–exercise score	.00045 (.00006, .00084)	.25	.03
	Wall-sits	.00169 (.00051, .00288)	.29	.01
	Age 18 y weight	.00450 (.00189, .00711)	.38	.001
Total body bone mineral gain, ages 12–18 y, R^2 = .46	Age at visit 11	−224.605 (−297.306, −151.903)	−.58	<.0001
	Age 18 y weight	11.488 (7.2510, 15.7254)	.54	<.0001
	Age of menarche	98.008 (53.643, 142.374)	.44	<.0001
	Maximum oxygen consumption	−8.430 (−13.7900, −3.0706)	−.32	.0048
	Wall-sits	2.115 (.05348, 4.17580)	.20	.80
Total body bone mass density gain, ages 12–18 y, R^2 = .15	Age at visit 11	−.02886 (−.05032, −.00740)	−.23	.04
	Age 18 y weight	.00139 (.00014, .00265)	.25	.03

ous investigations varied in age, size, and pubertal status; the bone measurements were made at different sites with different equipment; physical activity and calcium intakes were measured with different methods; and not all studies controlled for confounding variables.

Further, the timing of peak bone mass achievement is site-specific. In females, peak hip BMD is achieved in late adolescence, approximately age 16 years, whereas, maximum lumbar spine and total body BMD occur near 20 years of age.[32–34] Mention should also be made about measuring calcium intake. The number of days of food intake data required to estimate accurately mean daily calcium intake is not well-appreciated. In 2 comprehensive studies, 1 based on 365 consecutive days of food intake records by US adults and a second based on multiple 7-day diet records completed by 697 subjects from the United Kingdom, it was calculated that the number of days of food records needed to estimate mean daily calcium intakes within 10% of the true average for groups or individuals ranges from 7 to 88 days, depending on the specific methods used.[35,36] Dietary data collected with food frequency or food recall surveys that rely on the recollection of the subjects would be even more problematic. Thus, previous studies that used calcium intake recall data from 1 to 4 days were underpowered to estimate actual calcium intake.

Methods used in the present study included: 33 days of prospective food records collected from each subject over 6 years, a sports–exercise score based on 6 years of self-reported activities, total body bone mineral measurements made at ages 12 and 18 years, and dedicated hip bone measurements made at age 18 years. During the 6 years of this study, as the participants progressed from 12 to 18 years of age, 75% remained in the study. No relationship was observed between time-averaged calcium intake during ages 12 to 16 years with either total body bone mineral gain or hip BMD at age 18 years. In contrast, we observed that although the teenage sports–exercise scores were not associated with total body bone gain during ages 12 to 18 years, they were associated with increased hip BMD at age 18 years. The magnitude of the relationship is biologically important. The correlation of $r = .42$ would explain 18% of the variance in hip density in this study cohort.

An increase of .05 g/cm^2 of hip bone density has been projected to represent a 50% reduction in osteoporotic fracture risk.[37] In this study, a difference of .05 g/cm^2 in hip bone density (interpolated from Fig 1A) was associated with the amount of physical activity that distinguishes a primarily sedentary teenager from one who engages in some form of exercise on a nearly daily basis. Despite the established benefits of regular exercise, we are becoming an increasingly sedentary culture. The decline in our physical activity is illustrated by the fact that total caloric intake for teenage women has decreased from ~2300 kcal/day in l932 to ~1700 to 1800 kcal/day today, while body weight has increased slightly.[38–40] This difference of 500 kcal/day is equivalent to the energy used in walking 5 miles.

Despite this study's longitudinal design, its high participant retention, and the repeated measures made by the same study team, the observations are limited to a cohort of healthy young women representative of non-Hispanic, white females attending public schools in Pennsylvania. Mean daily calcium intake of the cohort was 919 mg/day at age 12 years and 926 mg/day at age 18 years, which is lower than the recommended daily allowance (1200 mg/day) and slightly higher than the national average of 833 mg/day for this group by age and ethnicity.[41] A limitation in this study is the fact that we did not have subjects with habitual calcium intakes of <500 mg/day. However, >75% of US girls in this age group consume >500 mg calcium/day.[42] Follow-up studies are needed to determine whether our findings apply to other populations of young women and to translate the observed exercise-related increase in peak hip BMD into public health concepts.

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